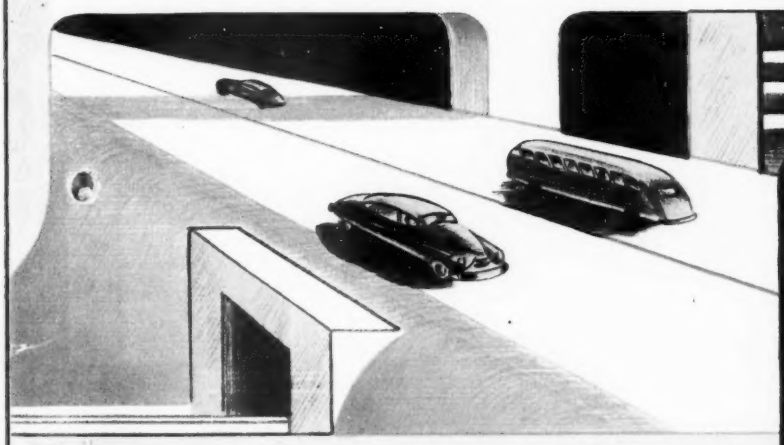
The CRUSHED STONE JOURNAL



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In This Issue

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- **Interregional Highway System and the Federal-Aid Secondary Road Program**
- **Added Federal-Aid Funds For Airports**

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The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

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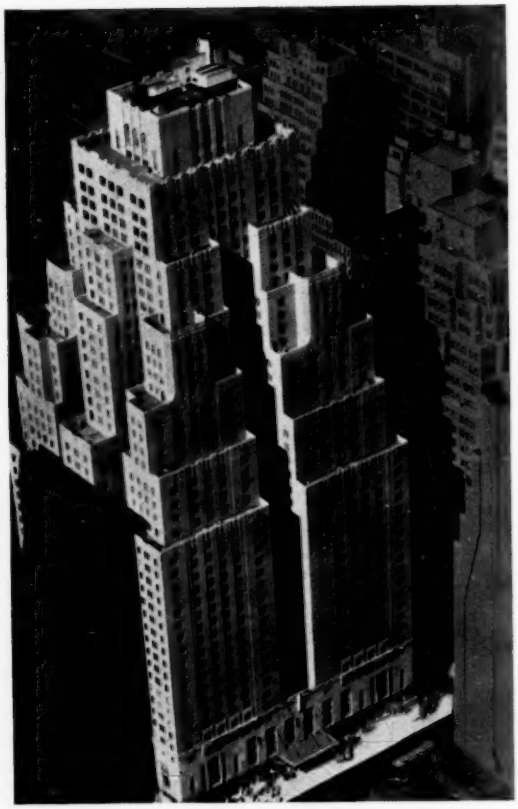

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The Problem of Flexible Pavement Design[1]

By A. T. GOLDBECK

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Washington, D. C.

IT WILL be well at the outset to get clearly in mind exactly what is meant by a flexible pavement. There are two general types of pavements, the so-called rigid pavement and the flexible or non-rigid pavement, and also there are pavements, the component parts of which come into either of these two categories.

The rigid type is generally made of concrete, or reinforced concrete, and it includes, also, monolithic brick. Modifications of the rigid type also include concrete base upon which is supported a wearing surface of bituminous concrete or other type of non-rigid surface such as brick or block with a bituminous filler.

The flexible type includes pavements such as bituminous concrete on a macadam, crusher run stone, gravel or sand-clay base. These two types, rigid and flexible, have different structural characteristics and their ability to support the wheel loads of traffic depends upon entirely different mechanical principles. For illustration, the concrete or rigid type has the ability to resist bending; it has beam or slab strength and when a wheel load is applied it bends the slab and produces internal forces or "stresses" as they are called. The bigger the load the higher will those internal stresses become. In general the stresses due to the bending effect of traffic loads are the same on the top and bottom of the slab, only they are opposite in character, one being a compressive stress and the other a tensile stress. Concrete is roughly seven times as strong in compression as in tension as produced by bending, and, consequently, bending of the slab always causes failure on the tension side. If the tension exceeds the tensile resistance, a crack will be produced and failure of the slab occurs.

There are still other bending stresses in concrete pavements than those produced by traffic. For illustration, during the day the top of the slab becomes hotter than the bottom, the slab humps itself up at the center and its dead weight then goes into action and tends to bend it down, thus producing high internal tension at the bottom which if high enough will produce cracking at the bottom. At night the reverse is true; the top cools and the bottom remains at more nearly a constant temperature. Consequently, the sides and corners are bent up and actually leave the subgrade and now the dead weight of the sides and corners tends to bend them down, and in so doing, tension is produced in the top. These thermal stresses, as they are called, sometimes are as great as roughly 50 per cent of the stresses due to loads, and they aid the traffic loads in causing failure. Still other bending stresses are produced by differences in moisture from top to bottom of the slab and these too must be considered in their effect on the cracking produced. The rigidity of the slab is such that a concrete pavement cannot suffer sharp bending without cracking. By the same token this rigidity of the concrete is beneficial and because of it the load is spread over a considerable area of the subgrade and thus the subgrade pressures are smaller than is the case with surfaces of the non-rigid type.

[1] Presented before New York State Highway Engineers Association, Syracuse, New York, March 22, 1948.

The non-rigid pavement has entirely different structural characteristics than the rigid type. It is incapable of resisting bending due to loads at rest and probably resists bending to only a minor degree under moving loads. Possibly a black base may have

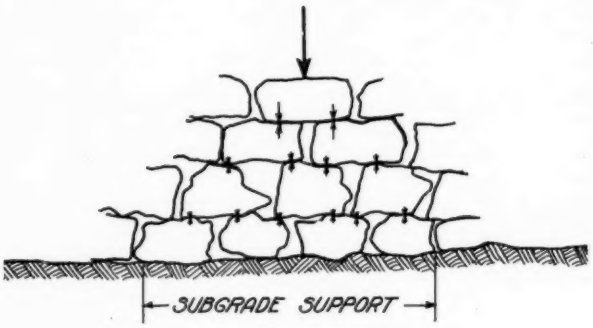


FIGURE 1
How Vertical Load Is Carried to Subgrade Through Uncompacted Stone

some bending resistance under moving loads especially in cold weather but not so much in hot weather. At any rate, it is safer to consider that the flexible or non-rigid type has no bending resistance but that it spreads the load to the subgrade in some other way. One can visualize how a load at the top of a flexible pavement can be spread over a considerable area of the subgrade by thinking of the pavement as being made up of layers of blocks, one layer resting on the other. The load on one of the blocks in the top layer is transmitted to say three or four blocks upon which it rests and the load on each of the three or four blocks in turn is spread over three or four blocks on the layer below and so on until the subgrade is reached. This load distributing effect in a non-rigid pavement is illustrated in Fig. 1.

Actually Fig. 1 is not a true picture of the load spreading possibilities of a well compacted flexible pavement for it applies only to loosely laid stone. When a pavement such as a well rolled and filled macadam is laid, the stone is wedged into place, considerable friction and mechanical bond are developed and a truer picture of the internal forces is shown in Fig. 2. In a well compacted surface there is accordingly a wider spread of the load to the subgrade than in a layer of loosely laid and uncompacted stone. The greater load supporting capacity of a compacted layer as compared with that of a loose layer is common knowledge and the reason is indicated by a comparison of the two illustrations given.

If there is a weak spot of any considerable diameter in the subgrade, the flexible surface, having no or at most weak resistance to tension or pulling apart would be incapable of spanning that spot, especially under a standing load, and it would tend to settle until again in contact with the subgrade. If the settlement is great enough to cause cracking, ingress for surface water or for soft subgrade material is provided and structural failure can ensue. Sketchily, then, a picture has been drawn to show the differences in the mechanical behaviour of the rigid and non-rigid types of pavement and quite obviously these differences must be taken into account if any attempt is made to get at the design of the flexible pavement in as logical and rational a manner as possible.

What is Meant by Flexible Pavement Design

Just what is meant by "design" as applied to the flexible pavement? It means first of all a determination of the over-all thickness necessary to carry the heavy wheel loads of traffic without damaging distortion and, second the determination of the compositions and thicknesses of the several layers, the subbase, base course and surface course or other courses, to the end that the most economical pavement will result. Third, it means the design of the cross-section so that the edges may have approximately the same strength as the center and, as a matter of course, it will involve proper drainage design just as required in all pavements.

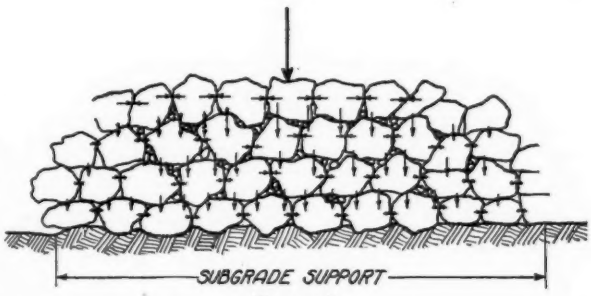


FIGURE 2
How Compaction Develops Horizontal Force and Hence Friction Which Aids in Transmitting Vertical Pressures Over Larger Areas Than When Stone Is Uncompacted

Some Fundamental Principles Involved

In order to develop a logical means for design it will be necessary to consider certain fundamental and pertinent principles making use of such information as may have been developed by past investiga-

tions. As has been shown, the loads of traffic are spread over the subgrade by the flexible pavement, and a little study of Figs. 1 and 2 will show very clearly that the pressures on the subgrade due to a wheel load cannot be uniform in amount. Actually the highest subgrade pressure occurs immediately under the center of the area of contact between the tire and the road. These pressures become less and less at greater depths and innumerable measurements and the use of well substantiated theory have demonstrated time and again that this is so. A curve showing how subgrade pressures are distributed, as actually determined by tests, is as indicated in Fig. 3. As can be seen, the subgrade pressures are greatest under the center of the load and they increase as the load increases.

Not only are pressures created on the subgrade immediately under the pavement, but pressures are created also in the subgrade at lower levels and these vertical pressures decrease in intensity the greater the depth and likewise they become more widespread. This fact has been shown by pressure measurements made at different depths and the results of these measurements are shown in Figs. 4 and 5. The pressures shown are the vertical pressures existing under fills of different depths, the fills having been placed on a concrete slab and to this extent the conditions differ from those in a subgrade. However, the pressures shown are similar to those in a subgrade.

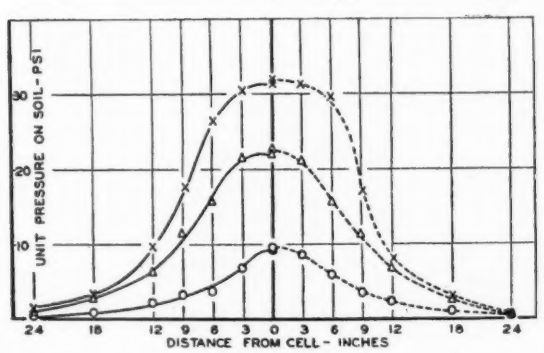
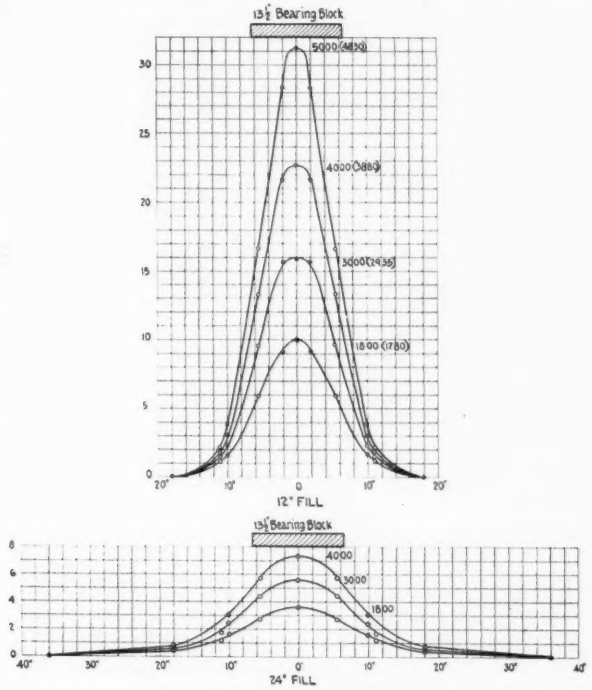


FIGURE 3
Pressures on the Subgrade Under 8 in. of Screenings

Whenever a material of any kind is subjected to load which creates internal force or stress, that material is deformed from its original shape, and the greater the internal stress the greater will be the deformation. So a subgrade immediately under a wheel load becomes deformed or compressed vertically by virtue of the vertical internal stresses in it due to the wheel load. Obviously more vertical compression takes place in the top layer than in layers lower down because, as seen, the very highest vertical stresses occur in the top layers. The compression or vertical deformation of the various layers, however, when summed up, will give the accumulated vertical movement of the subgrade just under the pavement and the vertical compression of



PRESSURE DISTRIBUTION THROUGH DAMP SAND FILLS

Pressure applied through 13½" circular bearing block.

Ordinates represent pressure in pounds per square inch. Abscissas show lateral distribution in inches.

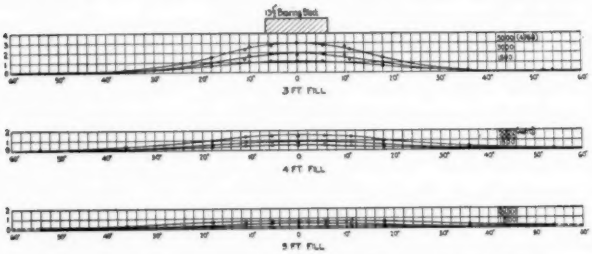
Note: Numbers in parentheses are values of reactions calculated from curves. Numbers outside of parentheses are loads applied.

Courtesy Public Roads Administration

FIGURE 4
Curves Showing Pressures at Different Levels in the Subgrade

the pavement when added to this accumulated vertical subgrade movement will be the vertical motion of the pavement surface due to the wheel load.

Quite obviously the pavement surface bends down in a curved shape just as it should because of the way the subgrade pressures are distributed. If the curvature of the surface under load is too sharp, due



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Courtesy Public Roads Administration

FIGURE 5

Curves Showing Pressures at Different Levels in the Subgrade

to too much deflection, cracking occurs and surface water can then reach the subgrade, soften it and failure can ensue. Obviously then the subgrade pressures must be kept small enough so that the accumulated subgrade deformations will not result in too much bending of the surface under load. Just what constitutes too much bending is not easy to define in the absence of specific knowledge, but certainly it seems evident that at no time should the maximum pressures on the subgrade be allowed to reach a value which will cause the material to continue to flow at an excessive rate.

The maximum pressure intensity on the subgrade produced by the wheel load should not exceed the bearing capacity of the soil. But this statement is not as simple as it may seem and a number of questions immediately arise such as, At what moisture and compaction condition should the bearing value be determined? What size bearing area should be used for determining the bearing value? These are things which are important and are now matters of judgment based on such knowledge as exists on the subject. My own judgment would lead me to the belief that the kind of bearing value of the subgrade needed for safe but economical design is that determined as follows:

1. The subgrade should be brought to the condition of compaction and moisture it will have under the worst conditions apt to exist. This will correspond to that degree of compaction obtained, at optimum moisture content for granular soils and at the plastic limit for heavy clay soils, by the AASHO standard method for "The Compaction and Density of Soil," T 99-38.

2. For making field tests, the depth and width receiving such compaction should be roughly 24 in. deep and 5 ft. in diameter.

3. The area of the bearing block should be about the same as the contact area of the tire with the road surface.

4. The load should be applied in increments, allowing each increment to remain a definite period of time, say 5 min., before the next load application.

5. By studying the load-indentation curve and by taking into consideration such matters as any sudden change in curvature, any obvious sudden increase in flow, or an approach to too great a total indentation, say over 0.3 in., some judgment may be formed as to what may be a reasonable and safe bearing value for the particular subgrade in question. Great accuracy need not be expected and is not necessary.

How to Determine Pavement Thickness

A great many ways have now been proposed for arriving at the safe thickness of a flexible pavement. All of them are necessarily approximate and they all involve the use of judgment, and so does the design of a concrete pavement, and in fact practically all other structures. The engineer must reinforce his judgment by as much reliable information as possible to support his judgment.

We have been called upon a number of times to say how thick airport runways of the flexible type should be to support heavy planes. There was no reliable theory available and so we made a large number of tests to determine how the subgrade was affected by loads applied through surfaces of different thickness. You are not interested in the details of these tests or the test methods, but you will be more concerned with the results which we finally generalized into a theory for determination of thickness—just as we now have formulas for determining the thickness of concrete pavements.

Our tests showed us that subgrade pressures under flexible pavements always take the shape shown in Fig. 3, but the thicker the surfacing the less are the subgrade pressures for a given wheel load. Other

matters also influenced the pressures such as the magnitude of the load, the size of bearing area and whether a single or a dual tire carried the load, the rigidity of the surfacing and other factors. It seemed, however, that not too much liberty would be taken with the results if they were generalized in a manner which will be explained in connection with the development of the following very simple theory:

It seems to be a fundamental conception that any wheel load on the surface must eventually be supported by the underlying subgrade no matter how it may be transmitted through the road surfacing material. If the surfacing is thin, and has no coherence or bending resistance, the area of the subgrade which supports the load is small as compared with the subgrade area which is brought into action when the surfacing is thicker or is more rigid. Accordingly since the subgrade pressures support the load which produces them, we could if we knew enough, write a formula which, in mathematical terms, would say that the downward load equals the upward subgrade pressures distributed in the form of a curve such as previously shown. If the peak of the curve of subgrade pressures created by the wheel load exceeds the bearing value of the subgrade, too much compression of the subgrade might take place and since the surfacing is not rigid, it would deflect downward with the subgrade and the excessive resulting bending could start a failure in that surface.

A highway pavement, even a concrete pavement, is never designed with much of a safety factor and there seems to be no reason economically to design a flexible type with too much of a safety factor either. For this reason, it is logical to allow the maximum pressure, which takes place only in a small spot in the subgrade directly under the load, to equal the bearing value of the subgrade, but not exceed it. There is another reason for allowing the subgrade pressure to approach the unsafe limit in one spot, namely, the fact that since the subgrade is somewhat plastic it will readjust itself under excessive load and thus bring a greater supporting area into play.

Analysis of a large number of tests seemed to indicate that, for all practical purposes, under conditions of surface and subgrade approaching those encountered in highways, the peak of the pressures actually produced is just about twice the equivalent uniform pressure confined within 45-degree lines sloping outward from the tire contact area.

Referring to Fig. 6 there are shown the necessary conditions in graphical form to understand the simple mechanics used to develop an expression for thickness of the flexible pavement.

As before explained, the actual pressures measured on the subgrade take the form of a curve of distribution such as shown by the curve labeled, "Actual Pressure Distribution," in Fig. 6. Any attempt to use this pressure curve directly in the development of a practical theory of design would no doubt present mathematical difficulties. To avoid these, recourse is had to an expedient which is frequently used elsewhere, namely to substitute for this actual pressure curve an imaginary equivalent uniform pressure which is assumed to exist on the subgrade over an elliptical area confined within 45-degree lines drawn from the tire imprint area in the manner shown in Fig. 6. Let it be emphasized that this uniform pressure does not exist; it is purely a mathematical device used to properly make use of the actual and more complicated pressures. This same kind of device or expedient has been used in the development of other theory such as involved in reinforced concrete.

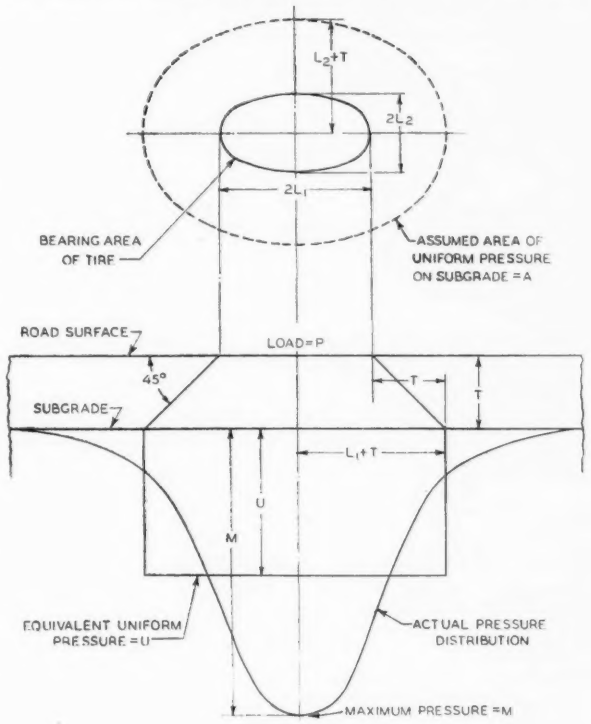


FIGURE 6
Case of a Single Load

Referring to Fig. 6 the elliptical area of the assumed equivalent uniform pressure on the subgrade $= \pi (L_1+T)(L_2+T)$ ..... (1)
and this equivalent uniform pressure equals the wheel load divided by the area over which this uniform pressure is distributed, or

$$U = \frac{P}{\pi (L_1+T)(L_2+T)} \quad \text{..... (2)}$$

We want the thickness T and from (2) it follows that:

$$T = \sqrt{\frac{P}{\pi U} + \left[\frac{1}{2}(L_1+L_2)\right]^2 - L_1 L_2} - \frac{1}{2}(L_1+L_2) \quad \text{..... (3)}$$

For all practical purposes this uniform pressure U is ½ of the actual maximum pressure which as stated may be safely considered as being equal to the subgrade bearing value M. Thus $U = M/2$ and when that value for U is introduced into (3) and when L_1 is considered equal to $2L_2$, there results a very simple design formula.

$$T = \sqrt{\frac{2P}{\pi M}} - \frac{3L_2}{2} \quad \text{..... (4)}$$

A design problem will show how this method may be used to obtain a good idea of what the over-all thickness of the non-rigid road surface should be.

Let the wheel load P = 8000 lb. carried on a single tire 13.50 × 24, having an inflation pressure of 82.5 lb.

Suppose it has been determined by load tests or by an approximation as described later that the subgrade has a bearing value of 30 psi. The first thing to calculate is the contact area of the tire with the road surface.

$$\text{This is } \frac{P}{1.1 \times \text{tire pressure}} = \frac{8000}{1.1 \times 82.5} = 88 \text{ sq. in.}$$

It is elliptical in shape and has a major axis twice the minor axis, that is, $L_1 = 2L_2$.

Tire contact area $= \pi(L_2 \times 2L_2)$, 88 sq. in. $= 2\pi L_2^2$

$$\text{So } L_2 + \sqrt{\frac{88}{2\pi}} = 3.74$$

$$T = \sqrt{\frac{2P}{\pi M}} - \frac{3L_2}{2} = \sqrt{\frac{2 \times 8000}{\pi \times 30}} - \frac{3 \times 3.74}{2}$$

$$= 13.0 - 5.6 = 7.4 \text{ in. thick}$$

say, 7.5 in.

The greater the tire contact area the greater will be the spread of the pressures and naturally a wheel load on dual tires would be spread over a wider area of subgrade than the same load on a single tire, and the thickness of pavement surface need not be as great. In Fig. 7 is shown how the pressures can and do spread themselves over the subgrade under dual tires and by equating the load P to the equivalent uniform upward pressure the thickness of surface necessary to support the load on dual tires may be arrived at in terms of known values.

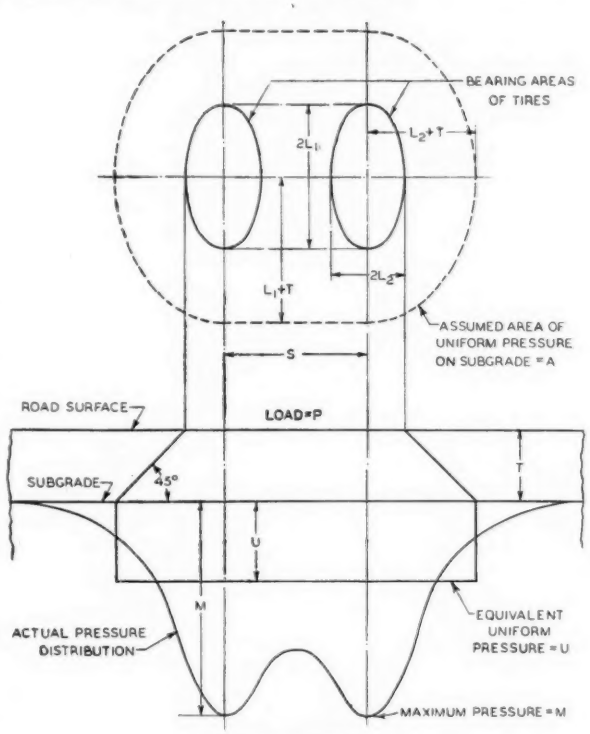


FIGURE 7
Case of the Dual Tire Loads

Without going into the details of the derivation, the thickness of flexible surface necessary to support a load on dual tires may be calculated as follows:

$$T = \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} - \frac{B}{2\pi} \quad \text{..... (5)}$$

Where $B = 2S + \pi (L_1 + L_2)$

$$C = \frac{Pk}{M\pi} - \frac{2SL_1}{\pi} - L_1 L_2$$

where A = area of equivalent uniform subgrade pressure
P = wheel load
U = equivalent uniform pressure over area A
M = maximum subgrade pressure and also the bearing value of the subgrade
S = center to center spacing of dual tires
L_1 = half major axis of tire contact area
L_2 = half minor axis of tire contact area

$$k = \frac{M}{U} \text{ assumed to be } = 2$$

or assuming $k = 2$, and $L_1 = 2L_2$

$$B = 2S + 3\pi L_2$$

$$C = \frac{2P}{M\pi} - \frac{4SL_2}{\pi} - 2L_2^2$$

Let the same example be assumed as before except that dual tires will be used instead of a large single tire.

An 8000 lb. wheel load would be carried on two 9.75×20 tires having 70 lb. air pressure and 12 in. spacing center to center. (S = 12 in.)

$$\text{The area of contact} = \frac{4000}{1.1 \times 70} = 52 \text{ sq. in} = \pi L_1 L_2 = \pi 2 L_2^2$$

$$L_2 = \sqrt{\frac{52}{2\pi}} = 2.87$$

$$B = 2S + 3\pi L_2 = 2 \times 12 + 3\pi \times 2.87 = 24 + 27.1 = 51.1$$

$$C = \frac{2 \times 8000}{30 \times \pi} - \frac{4 \times 12 \times 2.87}{\pi} - 2 \times 2.87^2 = 169 - 44.0 - 16.5 = 108.5$$

$$T = \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} - \frac{B}{2\pi} = \sqrt{\left(\frac{51.1}{2\pi}\right)^2 + 108.5} - \frac{51.1}{2\pi}$$

$$= \sqrt{66.4 + 108.5} - 8.1 = 13.2 - 8.1 = 5.1$$

So the 8000 lb. wheel load on dual tires requires only 5.1 in. of thickness on a 30 lb. subgrade as against about 7.5 in. when a single tire is used. The importance of taking account of the tire equipment is thus very evident.

There is one principal objection which has been voiced against this method, namely the fact that the so-called "bearing value" (M) is not too easy to obtain in the field and the fact that it would be much more desirable if a sample of the subgrade could be shipped to the laboratory and by means of proper laboratory determinations the supporting characteristics of the soil determined. This is not so far-fetched as it may seem, and one of the most widely used methods for flexible pavement design is based on a laboratory determination of the so-called California Bearing Ratio. This method is fully covered in the literature, particularly in Chapter X of the Engineering Manual of the Army Service Forces dealing with the Design of Runways, Aprons and Taxiways.

The California Bearing Ratio Test is made by compacting the subgrade soil in a 6 in. cylinder mold 7 in. high, using a standard compaction method which need not be described in detail at present. The sample is then saturated by placing the mold in water to a depth ½ in. below the top of the mold. The reason for this is the belief that eventually all subgrades will become saturated. After all free water is drained off, load is applied through a plunger of 2 in. nominal diameter and the loads are obtained at various penetrations of the plunger. The C. B. R. is then obtained at different penetrations in comparison with standard loads required for similar penetrations in crushed stone which is taken as the standard of comparison.

The load required at 0.1 or 0.2 penetration compared with the following values for crushed stone, is the so-called California Bearing Ratio:

Penetration in.	Standard Load psi.
0.1	1000
0.2	1500
0.3	1900
0.4	2300
0.5	2600

Suppose for illustration that at 0.2 in. penetration the greatest load occurs and equals 300 lb. The C. B. R. then $= \frac{300}{1500} = 0.2$ or 20 per cent.

Arbitrarily, a set of curves has been proposed giving the pavement thickness required for given wheel loads on soils having a laboratory determined California Bearing Ratio. Apparently no account is taken of the tire equipment and there seems to have been no rational basis for drawing the curves of pavement thickness except the judgment of those who were responsible for this design method. This method does not depart too far from the more rational method that has been explained to you in some detail.

The California Bearing Ratio method is of considerable interest in that it may ultimately permit of making laboratory tests to determine the really essential bearing characteristics of subgrade soils. Even now there seems to be reason for employing it as a rough approximation of the bearing capacity of soils for use in the formulas for thickness. For illustration, the chart in Fig. 8 shows an attempt to correlate the various physical characteristics of soils and it is interesting to note that a relationship is shown between bearing value M such as used in the formulas for thickness (formulas 4 and 5) and the California Bearing Ratio. These relationships can only be approximate but they probably are not too approximate considering the nature of the problem of pavement thickness design. Such a chart suggests that by making the necessary tests for classifying the subgrade and for determining the C. B. R. a very good estimate of the bearing value M of the soil for use in the design formulas can be obtained.

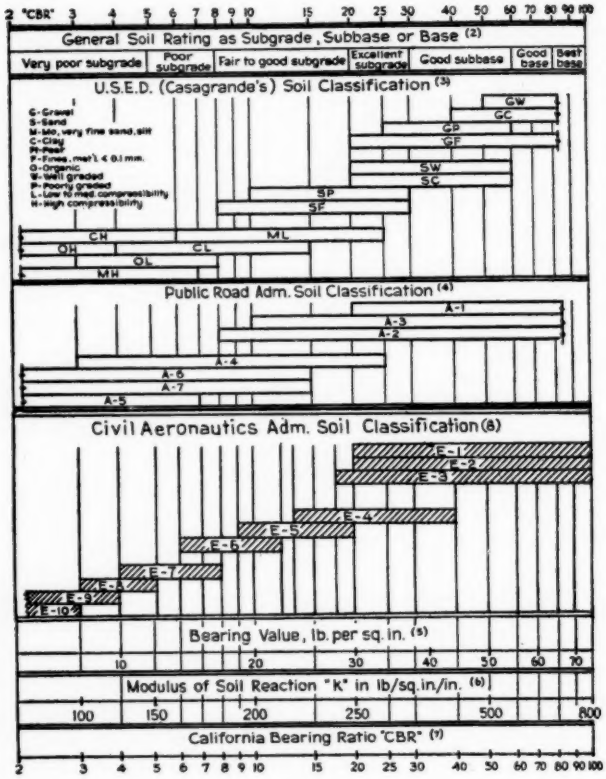

"CBR"
General Soil Rating as Subgrade, Subbase or Base (2)
Very poor subgrade
Poor subgrade
Fair to good subgrade
Excellent subgrade
Good subbase
Good base
Best base
U.S.E.D. (Casagrande's) Soil Classification (3)
Public Road Adm. Soil Classification (4)
Civil Aeronautics Adm. Soil Classification (8)
Bearing Value, lb. per sq. in. (5)
Modulus of Soil Reaction "K" in lb/sq.in/in. (6)
California Bearing Ratio "CBR" (7)

FIGURE 8

Correlation of Physical Characteristics of Soils(1)

(1) All interrelationships are very approximate. Actual field and laboratory tests are required to determine "k," "CBR," and bearing values.

(2) See "Foundations for Flexible Pavement," by O. J. Porter, 22nd AN. Mtg. Highway Research Board, 1942, for basic idea.

(3) See Engineering Manual, Chapter XX, March, 1943, War Dept. Office of the Chief of Engineers. See also, "Soil Tests for Design Runway Pavements," by Middlebrooks & Bertran, 22nd An. Mtg. H.R.B., 1942.

(4) See item (3) A-6 and A-7 soils cut off at CBR=15, rather than 25 as indicated in Chapter XX. CBR for A-5 soils of volcanic origin etc., may range above 7 and go as high as +80.

(5) See second reference of item (3), page 184. Bearing values measured as 0.1 in. deflection. Bearing plate area not given.

(6) See item (3) "k" is factor used in Westergaard's Analysis for thickness of Portland cement concrete.

(7) See items (2) and (3).

(8) Prepared by W. R. Macatee from information furnished by CAA Staff and CAA-Publication, "Design Manual for Airport Pavements," March 1, 1944.

NOTE: *The above chart was published by Roads and Streets, June 1944, and was later modified by W. R. Macatee of The Asphalt Institute as above indicated. The original chart was used by Earl J. Felt of the Portland Cement Association before a joint meeting of the Chicago Engineers' Club and the Illinois Section of the A.S.C.E., February 10, 1944.*

For example, suppose a laboratory test showed the soil sample to have a C. B. R. of 20, roughly, the bearing value M to use in design formula would be 30 psi.

What Should Be the Thickness and Nature of the Different Courses

It has been shown that in an earth fill under a concentrated load the greatest internal vertical pressures are at the top and they rapidly decrease at increased depths. It is obvious that the internal horizontal forces due to tractive effort or due to braking, are also greatest at the top of the pavement and they spread out and decrease at greater depths. Obviously then in any pavement the strongest and most stable material is demanded at the top and it can be and for economy should be weaker and less stable at the bottom near the subgrade. It is clear, then, that the sub-base should be somewhat better material than the subgrade; the base course should be more stable than the sub-base, and the surface course should be of the very highest strength. But how thick should the courses be? There is a somewhat rational way of determining these thicknesses and perhaps a numerical example will best illustrate how to determine these by calculation.

Suggested Design for 12,000 lb. Wheel Load

Assume a rather poor subgrade which will require a considerable total pavement thickness. Assume that the following materials are available:

Materials	California Bearing Ratio (C. B. R.)	Corres. Bearing Value (M)
Subgrade	4	10
Stable soil or gravel sub-base	15	25
Macadam	100	75
Bituminous concrete surface	100	75

Suitable tire equipment for a 12,000 lb. wheel load would be 11.25 × 22, 80 lb. air pressure, 14 in. c.c. spacing = S.

$$\text{Tire contact area} = \frac{6000}{1.1 \times 80} = 68.2 \text{ sq. in.} = \pi L_1 L_2 = \pi \times 2 L_2^2$$

$$L_2 = \sqrt{\frac{68.2}{2\pi}} = 3.17 \text{ in.}$$

$$T = \sqrt{\left(\frac{B}{2\pi}\right)^2 + C} - \frac{B}{2\pi}$$

$$B = 2S + 3\pi L_2,\ B = 2 \times 14 + 3\pi \times 3.17 = 57.7$$

$$C = \frac{2P}{\pi M} - \frac{4SL_2}{\pi} - 2L_2^2$$

$$C = \frac{2\times12{,}000}{\pi\times10} - \frac{4\times14\times3.17}{\pi} - 2\times3.17^2 = 688.1$$

For thickness above sub-base,

$$C = \frac{2\times12{,}000}{\pi\times25} - \frac{4\times14\times3.17}{\pi} - 2\times3.17^2 = 230.1$$

Over-all thickness,

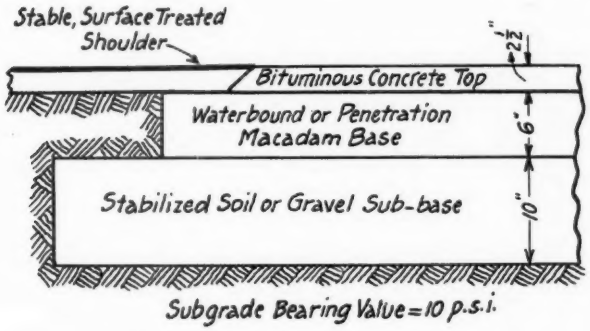
$$T = \sqrt{\left(\frac{57.7}{2\pi}\right)^2 + 688.1} - \frac{57.7}{2\pi} = \sqrt{84.3 + 688.1} - 9.2$$
$$= 27.8 - 9.2 = 18.6$$

Thickness above sub-base,

$$T = \sqrt{\left(\frac{57.7}{2\pi}\right)^2 + 230.1} - \frac{57.7}{2\pi} = \sqrt{84.3 + 230.1} - 9.2$$
$$= 17.8 - 9.2 = 8.6$$

The sub-base of stable soil or gravel should be 18.6 — 8.6 = 10 in. thick.

The base plus surface course is 8.6 in. thick, or say 8.5 in., and it is suggested that this be made up of 6 in. waterbound macadam and 2½ in. of hot mix.



TYPICAL DESIGN FOR 12000 LB WHEEL LOAD ON DUAL TIRES — RELATIVELY POOR SUBGRADE

FIGURE 9
Typical Design Resulting from Calculations

Design of Cross-Section

Just as in a concrete pavement, the weakest portion of a flexible pavement is along the sides. When a wheel load is at the side of the pavement, the pressures extend out in all directions and unless the side next to the shoulder is strengthened, the subgrade pressures will be too high and failure may result. It is advisable to use a "stepped" construction making the foundation course wider than the surface and the sub-base wider than the foundation using steps along at least a 45-degree slope each time. The design of a cross-section suitable for the above conditions would be as in Fig. 9.

Other methods for designing flexible pavement are advocated by different individuals. A number of states have now proposed their own methods suitable to their locality and fitting their needs. The method just described is supposed to be on the conservative side, but this is a good fault for if any great thickness due to poor subgrades is indicated, this thickness will be made up by an extra thickness of the cheaper sub-base material. Such material may be a better grade of soil than the subgrade, or pit gravel, or similar granular material. Thus the more stable but more expensive aggregate for use in the base course and surface course may be kept to a minimum.

It is hoped that no one has received the impression that this or any method of pavement design is highly accurate for that is not so; they all involve approximations. However, the same is true of the recognized design methods employed for many kinds of structures. The method described however has a rational basis and it does aid one's engineering judgment. Furthermore, the thicknesses obtained with this method are not out of line with our general ideas of what flexible pavement thicknesses should be.

Air-Powered Light

How to provide adequate lighting on such jobs as shaft sinking, mining, quarrying, night construction, and other work where the scene of action changes quickly is often a problem.

One solution has been found by one company which has developed a small, portable, air-powered electric generator that takes its energy from compressed-air lines. The unit consumes 10 cfm. at 90 psi. pressure and delivers 150 watts at 115 volts. It will therefore serve two 75-watt lamps and one 150-watt light.

All working parts are compactly assembled in a case 7¼ inches long and 5 inches high, weighing 8¾ pounds, complete. It is provided with a handle to facilitate moving it from place to place.

The generator can be carried anywhere, and will operate under the most adverse conditions. Submergence in water, short circuits, or overloads will not damage it; and if its output terminals are shorted, light will be restored as soon as the short is removed. Another advantage claimed for it is that mine electricians and public utility men need not work on "hot" circuits, for even if the regular power supply is shut off the generator may be used to furnish the light necessary for making repairs.

—*Compressed Air Magazine.*

Interregional Highway System and the Federal-Aid Secondary Road Program[1]

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PLANNING the interregional system had its official beginning with the approval of the Federal-Aid Highway Act of 1938, which directed the Chief of the Bureau of Public Roads to investigate and report on the feasibility of constructing not exceeding three superhighways running east and west and three running north and south across the country, and the feasibility of financing them through a system of tolls.

Investigations of the six routes showed that such a system of superhighways was feasible of construction, that it would total 14,300 miles in length and would cost at then prevailing prices nearly three billion dollars to construct. The investigations also led to the conclusion that only about 40 per cent of the cost of constructing and operating such a system in its entirety could be expected to be returned in tolls.

Although the findings, published in the report, "Toll Roads and Free Roads," were strongly negative with respect to the feasibility of a nationwide system of toll highways, the over-all results were far from negative. The information that was assembled and analyzed in reaching the negative conclusion on toll roads served also to point the way to what in effect was a general outline of the first master highway plan for the nation.

For about three years most states had been engaged, with Public Roads cooperation, in the conduct of statewide highway planning surveys. The early results of this work, assembled for the first time on a national basis, began to show the real character of our highway usage.

Character of Highway Usage

One of the most striking new discoveries was the extremely small volume of long-range travel—that type of travel for which the transcontinental toll system was presumably intended—that existed. Only 300 vehicles per day were found to be traveling between all states on or near the eastern seaboard and the Pacific Coast States. On the contrary, the vast majority of highway trips were found to be very short. Forty per cent of those performed partially or wholly on rural roads were less than 5 miles in length, and 60 per cent covered less than 10 miles. Trips of 100 miles or more accounted for only 1 per cent of all trips. These last trips have more importance than their numbers indicate, for while they account for but 1 per cent of all trips, they account for 25 per cent of travel as measured in vehicle-miles. Nevertheless, it was at once apparent that a system intended for long-range travel, excluding by its very design trips less than 20 or 25 miles in length, would be performing the most limited service, and would largely ignore the real highway needs of the nation.

Such findings led to the investigation of a free system of greater extent that would serve this shorter range traffic, largely of city origin and destination, and at the same time provide adequately through proper route integration for such long-range travel as did exist. Thus part II of the report recommended as a part of a master plan for free highway development an interregional system of some 26,700 miles, not quite double the mileage included in the six toll superhighways investigated. This system would provide access to virtually all the larger cities of the nation, and was then expected to serve at least 12.5 per cent of all rural traffic. This figure compares with 1.2 per cent estimated to be served by the toll system.

While this report effectively stopped further federal interest in toll roads, it at the same time stimulated thinking on the need for a system of interregional highways, so much so that in April 1941 the President appointed the National Interregional Highway Committee, with instructions to recommend a limited system of national highways designed to improve interregional travel. This Committee elected Commissioner MacDonald chairman, and with staff assistance provided by Public Roads undertook a thorough reanalysis of the whole problem, using the much larger amount of data available at that time than in 1938. Then, in 1943, Congress

[1] Presented at the 31st Annual Convention of the National Crushed Stone Association, Netherland Plaza Hotel, Cincinnati, Ohio, January 26-28, 1948.

directed the Commissioner of Public Roads to report within 6 months on the need for a system of express highways. These dual requirements were satisfied by the transmittal to the President on January 5, 1944, of the report, "Interregional Highways," the report that served as the basis for the eventual designation of the National System of Interstate Highways.

The additional data available to the Committee served to fill in many of the gaps existing in early planning survey results and to emphasize still more the importance of the city as the place of origin and destination of traffic.

Importance of the City as a Traffic Generator

The importance of the city as a traffic generator is clearly shown by traffic flow maps, on which the bands invariably widen as they approach the urban areas. This effect is noticed for as much as 5 or 6 miles on either side of cities as small as 10,000 population and for distances up to 35 miles from the largest cities such as New York, Chicago, or Los Angeles.

Studies of the origin and destination of traffic give added factual proof of the place of the city as a generator. They show that 50 per cent of the traffic approaching even the smallest cities is destined to, and not beyond the city. For the largest cities this figure rises to as high as 95 per cent. They show also that 50 per cent of the traffic on main highways has both origin and destination in urban places, and that an additional 36 per cent has urban origin or destination, leaving only 14 per cent with both origin and destination in rural areas. And much of the traffic in the last category passes through one or more urban places en route.

Thus an interregional system to be most effective must interconnect as many cities as possible while at the same time provide reasonably direct connection between the important regions of the nation. It also must serve important areas of agricultural productivity, industrial concentration, and the principal scenic and recreational areas that attract tourists and vacationists in large numbers. Suitable international connections must be provided, and, not least in importance, the needs of the military establishment both in peace and war must be met.

Fortunately these requirements are not divergent, and routes selected to meet one condition usually satisfied others as well. The principal highway transportation need of the military, for example, is for routes that will provide for the rapid movement of men and material, principally material, in time of emergency. From that viewpoint the city is the major bottleneck, and a system that permits free movement between important areas in peacetime will serve equally well the military needs in wartime.

Development of Interregional System of Highways

So with these basic considerations in mind, the Committee explored the possibilities of seven systems ranging in length from the proposed toll system of 14,300 miles, to one of 78,800 miles, some of which had previously been studied in considerable detail by Public Roads.

Finally it was concluded that a system of 34,000 miles, 29,500 rural and 4,500 urban, that would accommodate on its rural portion an average traffic in 1941 of 2,660 vehicles per day would provide the most effective service per mile. Such a system, it was estimated, would serve directly all cities of 300,000 population or over, all but three of those between 100,000 and 300,000, and over half of all cities of 10,000 population or over. The routes would pass through one-third of the counties of the nation, in which resided 45 per cent of the rural population, and from which came 43 per cent of all agricultural production. In the cities and counties served were 22,000,000 of the 32,000,000 vehicles registered in 1941, and on the rural portion of the system would be found 20 per cent of the total rural travel. And this service would be provided by a system including only 1 per cent of the mileage of streets and highways of the nation.

In the report the Committee reiterated the critical importance of the city in our present day traffic problem and urged that routes into and through the urban areas be favored in the allocation of funds.

Emphasis Shifted to Urban Transportation

A change in emphasis from rural toward the urban sections of the federal-aid system was then due—perhaps overdue. The earlier job of providing reasonably adequate routes connecting the cities with one another was largely finished. While many miles of rural highway have been rebuilt and must be rebuilt again to accommodate the volumes and speeds of today's and tomorrow's traffic, the greatest challenge of the immediate future is to open up the cities. They must be made easily accessible from rural and suburban areas, and transportation within their limits must be freed from the shackles of congestion if the city is to assume its rightful place in our economy.

Probably in no phase of our American standard of living have we advanced so little over the past quarter century as in urban transportation. The Committee very properly believed that in the interregional system we would have the means of starting the campaign to bring to the city the type of transportation facility it must have. Much of the Committee report is devoted to a discussion of how the interregional routes could improve urban transportation and, more important, how by the coordination of highway planning and the planning of other phases of city development, these routes could serve to improve many other features of city life.

Moreover, urban problems deserve emphasis for another reason as well. Over the years the source of highway funds has gradually shifted from property taxes to the highway user, until now highway user revenues and highway expenditures are virtually in balance. And at present highway user taxes come almost equally from urban and rural users. Over the years past the bulk of the highway expenditures has been in rural areas, a proper allocation because of the city drivers' interest in and usage of rural highways and because the need for their improvement was so great. But now city traffic congestion has reached such magnitude that it is imperative in the interest of both the city and rural user that greater consideration be given the city in allocation of highway funds.

Design Standards Developed on Basis of Usage

The Committee recognized that the value of the system would be dependent not only on its extent and general location, but also on its design, and accordingly recommended design standards it believed would be in keeping with the intent and expected usage of the system. Such a system would be many years in realization and for most of its length, in rural areas, it would generally follow existing routes. Thus, when any project was initiated on a section of route that would eventually be a link in the completed system, it was essential that it be constructed to standards appropriate for an interregional highway.

Appropriate standards mean just that. They do not mean, as has been popularly supposed, depressed or elevated superhighways of two or three lanes in each direction crisscrossing the country. Some sections in urban areas will be so designed and some rural highways will have two lanes or sometimes more in each direction, separated by a dividing strip, with cross traffic carried at separated grades and traffic permitted to enter and leave only where it can do so with safety. But well over half the rural mileage will not within the foreseeable future require more than a total of two lanes.

Standards proposed for the interregional system were based on the results of exhaustive research on driver behavior begun several years earlier by Public Roads. This research revealed many characteristics of driver behavior and showed for the first time the influence of the driver, the vehicle, and the road on driving practice. It made possible the development of a series of standards of design that would insure that within the range of their capacity, the roads would continue to function as intended because they could be designed to fit the traffic.

Based on these studies the design speed for level rural country was set at 75 miles an hour and somewhat lower in rolling and mountainous areas, and standards for all design features set accordingly. Lane widths were established at 12 feet, 10-foot shoulders were provided throughout except in mountainous areas where expense would be prohibitive, and passing and stopping sight distances made consistent with the design speed.

A most important consideration for preserving the utility of the road is the provision of adequate numbers of lanes, and, on two-lane roads, the assurance of an adequate percentage of the road on which passings can be accomplished. The Committee decided that it should be made possible for a driver who so desires to average, over long distances, speeds of 50 to 55 miles an hour. To do so requires an ability to pass other cars without following them for undue distances, for much of the traffic will desire to move at speeds of 50 miles an hour or less. Thus the standards provided for two lanes or more in each direction wherever the traffic volume is expected to exceed 3,000 vehicles per day, and on all sections on which the volume is expected to be between 2,000 and 3,000 vehicles per day whenever the sight distance is not adequate for passing.

Another equally important provision for preserving the value of the road is the control of access. The Committee recommended that access be permitted only where facilities for safe entrance could be provided. Indiscriminate access encouraging uncontrolled and often undesirable roadside development is the reason for a large portion of the rural accidents and much of the obsolescence of our present highway systems. Without adequate access control there is no way of insuring that the value of our future main highways will be preserved.

These recommended standards would provide a system of balanced design, superior to that now used in any state. It is of interest, however, that there is no element of the standards that was not equalled or exceeded by one or more states in their current design practices. Some design for higher speed. Some have used wider lanes, and others wider shoulders. Some justify 4-lane design with lower volumes. But in no state had all elements been combined in such a way that roads currently being built would equal in permanent service value the roads that would be produced under the Committee's recommendations.

Congress Established National Interstate System of Highways

Thus ended the planning of the interregional system as such, although the planning of the detailed location and for the design of its individual sections was only beginning. The report of the Committee was transmitted to the Congress by the President on January 12, 1944, with his recommendation for early action. On December 20, 1944, the Federal-Aid Highway Act of 1944 was approved. This act included provision for the designation of a National System of Interstate Highways, to be established by joint action of the states with approval of the Administrator of the Federal Works Agency. It was to be made a part of the federal-aid system and was limited to 40,000 miles in length. Thus, no new system of highways was created, but up to that mileage of the 233,000 miles of the federal-aid system was to be designated as of first order of national importance. The act authorized no special funds for the interstate system, but consistent with the strong recommendation of the Committee that greater emphasis be given the urban problem, authorized $125,000,000 for each of the three years covered by the act for expenditure within urban areas. Although the act specifies only that these sums be spent on the federal-aid system within urban areas, it is to be expected that they will largely be allocated to projects on the interstate system, for it is on the routes now comprising that system that need for traffic relief is usually the greatest. Likewise it is to be expected that a substantial portion of funds authorized for construction on the federal-aid system, either rural or urban, will also be allocated to routes of the interstate system.

Soon after approval of the act, all states were requested to propose routes for inclusion in the system. Most proposed virtually the routes recommended by the Committee. A few proposed a much smaller mileage than that recommended in the particular states, and several considerably more. A number of differences very naturally arose in regard to state-line connections. All proposals were reviewed by Public Roads, the service that would be rendered by each route proposed by a state and not included in the Committee recommendation evaluated, and differences between states reconciled. A total of 45,556 miles was included in the states' proposals, which had to be reduced in compliance with the act. Eventually agreement was reached on a system of 37,681 miles in length, 34,799 miles in rural areas, and 2,882 miles in urban areas, and on August 12, 1947, six months ago, the Federal Works Administrator gave his formal approval.

This system as finally approved is virtually that proposed by the Committee. Now all cities of 100,000 or more population in 1940 are directly served, as are 182 of the 199 cities of 50,000 or more population. The 2,319 miles of the 40,000 miles allowable that were not designated are reserved for anticipated future use in providing circumferential and distributing routes in urban areas as the main lines are completed.

Steady Progress Made

Progress toward realization of the system has gone steadily forward without awaiting the formal approval of the system. First, to translate standards recommended by the Committee into working standards that the states would agree to follow, the Special Committee on Administrative Design Policies of the American Association of State Highway Officials immediately undertook a careful review of the Committee's recommendations. This group, composed of the foremost highway design engineers of the states, prepared a set of standards for the interstate system, following in general those recommended by the Interregional Committee, except in instances wherein it was felt that general attainment of the desired standards was not possible. These standards received approval of the Association by vote of the states on August 1, 1945, and are now accepted by the states and Public Roads as governing the design of all projects on the interstate system.

Immediately upon approval, these standards were applied to projects on any route expected to be included in the system, once it was formally designated. Thus, while a seemingly long time elapsed between passage of the act and approval of the sys-

tem, steady progress was being made toward a realization of the provisions of the act without awaiting technicality or formality, a tribute to the cooperative relations long established between the states and Public Roads.

The greatest challenge in the development of the interstate system obviously lies in the cities, and here progress is being made, although in too few localities is there evidence of actual construction. Urban problems were new both to state and federal officials, and unfortunately few cities were either ready with plans for suitable highway development or even equipped to prepare them.

First, city traffic needs had never been satisfactorily determined in any city, a situation that led to the development by Public Roads of an entirely new technique using home-interview methods, disregarding the routes now actually used in urban travel. Then there is the necessity of integrating highway plans with plans for other phases of the city development, and with plans for approaching rural highways. Finally there was the necessity of obtaining agreement not only between the state and the city, but often of finding a common ground on which various contending factions within the city could agree.

So in a field new to all of us, in which technical and administrative difficulties are great, and in which careful advance planning is both laborious and essential, the visible progress of the early years has been small. This was to be expected. The cities in which the greatest strides have been made are those such as Chicago, New York, and Los Angeles, where plans for needed improvements were ready, and in these cities much progress may be seen on the ground. Less conspicuous but just as vital progress has been made in many other cities, however. In over 60 urban areas, some involving 30 to 40 independent towns and cities, comprehensive studies of travel habits have been conducted by the home-interview method, and less intensive surveys have been completed in many more. In 100 cities, engineering reports have been completed or are to be made either by public agencies or by consultants. Progress has in fact been truly remarkable, considering the shortage of engineering personnel confronting every agency.

As to actual physical progress on the interstate system under the 1944 Act, 1,484 miles of road estimated to cost approximately $250,000,000 have been agreed upon up to December 31, 1947, for construction with federal-aid funds. Additional mileage estimated to cost $135,000,000 has been programmed, under the 1944 Act funds.

The Secondary Road Program

Now to jump to the secondary road program, which may seem quite unrelated to the interstate system. In one sense it is, yet in another it is directly related, for it is one element in the master highway plan for the nation just as is the interstate system.

Secondary roads were first mentioned in federal legislation in the Act of June 16, 1936, in which $25,000,000 for each of the two following fiscal years were authorized for expenditure on "secondary or feeder roads." Succeeding acts continued authorization, although somewhat smaller in amount, in the same general language. The 1944 Act, however, provided a much larger authorization—$150,000,000 annually. This act specified, moreover, that the funds were to be expended on the "principal" secondary and feeder roads, and further stipulated that projects must be on a system of secondary roads selected by the state highway departments in cooperation with the appropriate officials of each county and the Commissioner of Public Roads.

Thus the states and Public Roads were faced with the immediate task of selecting a secondary system in each county on which agreement with local officials could be obtained and developing suitable standards for the large mileage of light-traffic roads that will be included in those systems. Earlier secondary road construction had been largely confined to the more important roads, standards suitable for lightly traveled state highways were commonly used, and construction was accomplished by the usual contract method.

Expanded Program Required Significant Changes in Procedure

The expanded program required significant changes in this procedure. First, standards were developed for roads with average daily traffic volumes even below 100 vehicles. These standards for the lowest volume roads permit surface widths of 12 feet on 20-foot roadbeds, and in mountainout areas, grades up to 15 per cent. For the roads with larger volumes, higher standards are required, until for average daily volumes of 1,000 vehicles or over, usual federal-aid system standards apply. As in the case of the interstate standards, these secondary standards were developed by a Committee of the American Association of State Highway Officials, and also

officially approved by vote of the states on August 1, 1945. There is a significant difference, however, in that these standards were deliberately set low, with the belief that in most cases higher requirements would be found desirable, whereas the interstate standards were set at what was believed to be the maximum level attainable for uniform application the country over. These standards were reviewed and approved by the Board of Secondary Road Consultants appointed to advise Public Roads and the states and to assist in effecting workable liaison between state and county officials.

Another departure from customary state and Public Roads procedure was the acceptance of the performance of a considerable amount of construction by force account, when the counties were adequately equipped to perform satisfactory work. Contracting organizations equipped to handle the many small secondary projects are few indeed, so the use of county forces where feasible not only benefits the counties doing the work, but also those other counties which must rely on the contract procedure. Another departure from established state practice was the resort to greatly simplified plans and specifications.

Vital Need for Common Understanding and Recognition of Real Problem

With the technical and procedural details reasonably well worked out, the principal obstacle to be overcome in the rapid prosecution of the secondary road program is the lack of a common understanding and recognition of the real problem. In the selection of the system, for example, the requirements both of the law and of sound judgment are that it be confined to the principal secondary and feeder roads. Yet in many counties the principal roads are already improved to satisfactory standards and the pressure on the local officials is for the extension of some type of improvement to roads of much lesser importance. In a similar category is the question of determining priorities of projects once a system is established, a factor advanced quite generally as a reason for keeping the system small and thus limiting the choice of projects for construction. The character of improvement is likewise the subject of much concern and discussion. There are those who advocate extensive surfacing operations with little regard to grade or alinement improvements. These advocates do not recognize that improvement in one phase of a road's character almost automatically requires improvements in other phases as well. An improved surface will permit heavier loads and may thus require reconstruction of bridges. And likewise it may invite sufficiently higher speeds to necessitate alinement changes. The road must be considered as a whole, and if not first improved to ultimate desirable standards, whatever is done should be a step toward the final plan. Surface improvements on inappropriate alinement cannot be considered in this category.

The law and also sound judgment require that projects once constructed be adequately maintained. The responsibility for maintenance of federal-aid projects, primary or secondary, rests with the state, but many, if not most, secondary road projects are off the state systems. Here the counties will be faced with the job for maintenance, an obligation that may become too burdensome if the extent of the system and the type of its improvement are not carefully watched.

Administrative Practices to Vary Widely in Early Stages

In the course of time some approximately uniform pattern of administration undoubtedly will emerge. In the present very early stage of secondary road development, however, it is to be expected that administrative practices and general philosophies will vary widely throughout the country, and that is exactly the case. Some states have selected and received local and Public Roads approval of very large systems. One state's system includes 33,000 miles, or about one third of its rural road mileage. In others the system thus far approved barely covers the programmed projects. Similar wide differences appear in the types of projects and design standards. All approaches are undoubtedly justified under the particular conditions, yet all undoubtedly will draw more and more closely together as the programs progress.

Secondary Systems Related to Land Use

One feature that is emerging, particularly in the western states, is the growing recognition that the purpose of the secondary roads is mainly to serve the land. Consequently, the secondary systems and programs must be correlated with the present and anticipated land use, so that roads and land each may derive support from and help to support the other. In many counties active committees composed of local citizens and county and state officials meet

regularly to plan for the better utilization of their counties' land and other resources. Secondary road planning is an integral part of this general planning, and so long as it is considered in this light there can be little doubt that it is taking the right direction. Such local planning ventures will be followed with great interest and encouraged in every way possible for they represent the truly democratic principle of full local responsibility with support as needed from state and federal agencies.

Despite the administrative difficulties of organizing programs that will eventually include every one of our more than 3,000 counties, marked progress is being made in the secondary program, more conspicuous progress perhaps than in the urban program. Secondary systems totaling 364,000 miles had been approved as of December 1, 1947, in all states. Up to December 31, 35,122 miles of road had been programmed, estimated to cost $626,000,000, and $400,000,000 had been obligated for the construction of 22,737 miles.

The 1944 Act Opens New Era in Highway Development

The 1944 Act opens a new era in highway development. It implements the master plan for the highways of the nation first proposed a decade ago in "Toll Roads and Free Roads." The systems provided for in the act now offer opportunity through wise administration to bring appropriate improvement to all highways of the nation.

Consider the service rendered by these systems. First is the interstate system of 38,000 miles, the system of roads of highest order of importance, representing 1 per cent of the roads but serving 20 per cent of the traffic. Next in importance comes the remainder of the federal-aid system, totaling 195,000 miles, 7 per cent of the mileage, and serving another 37 per cent of the traffic. Finally comes the federal-aid secondary system consisting at present of 364,000 miles, 12 per cent of the mileage, and serving 23 per cent of the traffic. Thus the total mileage eligible for federal aid is now approximately 600,000 miles, about 20 per cent of all mileage. Yet it is estimated that this 20 per cent of the mileage serves 80 per cent of the traffic. As time goes on, routes will be added to the secondary system, the mileage of which cannot now be estimated, but if these additions bring that system to a length of 450,000 miles, we will have a total of 683,000 miles, still less than one quarter of all mileage, in which the Federal Government would have a share of the responsibility. This mileage would probably accommodate 85 per cent of the traffic, leaving only 15 per cent to be served by the remaining mileage of some 2,300,000 miles.

Major Difficulties Administrative Rather Than Technical

It is evident that the principal difficulties that will be encountered in developing this master highway plan will be administrative more than technical. Where in the past each state has had to work with one cooperator, the Federal Government, it now must also work with all counties and all urban areas within its boundaries, and carry out programs involving routes in the state system and on county roads as well.

Some states in the past, for ease in administration, brought their state systems into conformity with the primary federal-aid system. As the secondary program advances, these or other states may find it desirable to incorporate in their state systems the secondary systems as well, to facilitate administration, design and construction, maintenance, and operation. Roads of sufficient importance to be a federal responsibility, the primary and principal secondary roads, should certainly be of statewide interest as well, and may very properly be included in a state system. Roads of lesser importance—and these will be roads extremely low in the traffic scale —may logically be considered as a local responsibility. Thus, as the divergent administrative practices of the states inevitably are drawn closer together, we may well find a sharper and more realistic division of responsibility between state and local units based on traffic service. Taking under their own responsibility all routes of general traffic interest may lead the states also to sounder policies of returning road user revenues to the roads of general interest, and leaving the vast mileage of roads of purely local interest to be supported by funds from other sources. The new act offers great opportunity not only for the provision of more serviceable roads, but for the development of more effective highway administration as well.

Steadily Increasing Traffic Demands Will Severely Test Highway Plant in Years Ahead

We are making definite progress in this new era in highway development, despite high prices, material shortages, and a critical deficiency of engineering and administrative personnel. And it is well that

(*Continued on page 20*)

Added Federal-Aid Funds for Airports

By Walter R. Macatee

Manager, Airport Division
American Road Builders' Association
Washington, D. C.

SPONSORS of airport projects in states where ordinary apportionments of Federal-aid funds have become exhausted often secure Federal grants to cover a portion of the cost of their projects despite the exhaustion of such allotments. Where normal apportionments of Federal funds made to the states under the Federal Airport Act have become completely allocated, sponsors of airports who are "on their toes" do not despair. They look into the availability of still other Federal funds for developing their projects. This additional financial aid is frequently available from what is termed the discretionary fund.

Civil Aeronautics Administration officials make allocations from this fund only after the normal apportionment to the state in which the project is located has been completely allocated, tentatively or otherwise.

When resorting to the discretionary fund for aid in developing an airport, CAA's Administrator takes into account existing airport facilities in each of the states. And the need for or lack of development of airfield facilities in all of the states is likewise studied. On-the-job-sponsors who are keen to receive Federal-aid with which to develop their airports, but who might be located in states where normal allotments have become exhaused, and do not overlook the discretionary fund as a source of Federal-aid, often advance their projects' completion by showing need for prompt development of airfields in their particular locations. This is accomplished by grants from Civil Aeronautics Administration's reservoir of extra funds.

The discretionary fund—as the name connotes—is distributed on the basis of CAA's Administrator's judgment of the aeronautical needs at any set of locations. It represents twenty-five percent of net appropriations by Congress for carrying out the principal purpose of the Federal Airport Act; that is, granting financial aid to political sub-divisions for developing local public airports.

The balance, or 75 percent, of these appropriations is divided on a formula fixed by Congress by which one-half is apportioned to the states in proportion which the population of each state bears to the total population of all the states. And the other half is divided in proportion which the area of each state bears to the total area of all the states. These funds are likewise used as Federal-aid for developing local public airports.

No mathematical formula applies in distributing the discretionary fund. That portion of Federal appropriations to assist in developing airports is distributed by CAA's Administrator in a manner he deems most appropriate. He does this regardless of the states in which projects may be located, and for the sole purpose of accomplishing the National Airport Plan. That plan is to provide a system of public airports adequate to anticipate and meet the needs of civil aeronautics.

Total authorization of government funds which flow from the Federal Airport Act to assist in developing public airports in the states—to be spent over a 7-year period—is made up approximately as follows:

CAA-expenses	$ 25,000,000
Apportionments to States	356,250,000
Discretionary Fund	118,750,000
Total	$500,000,000

Before funds which Congress appropriates from time-to-time are allocated to pay the government's fifty percent share in developing most local airports, a portion is set aside for the Civil Aeronautics Administration. This is used for planning, research and administrative expenses.

Congress sets the amount CAA gets for expenses. This is usually five percent of each appropriation of Federal funds to assist sponsors of local airports. Seventy-five percent of the remainder is apportioned to the states on the formula already described. The other twenty-five percent makes up the much-sought-after discretionary fund. This goes to pay the Federal share of cost of essential projects regardless of state lines if the entire apportionments to states in which the projects are located have been assigned to other airports.

It is not the desire of Civil Aeronautics Administration officials to concentrate distribution of the discretionary fund to only a few states. They prefer to allocate the fund on basis of aeronautical needs, doing so reasonably evenly to all states. Nevertheless, sponsors of airports in states who are aggressive, as a group, in seeking Federal funds might conceivably receive more than their states' normal proportion of the discretionary fund, intended for airport development throughout the nation as a whole.

The discretionary fund serves a dual role. Its primary purpose is to provide a reserve of Federal-aid funds for developing much-needed airports, other than those which grow out of normal apportionments to the states. Secondly, and incidentally, it serves as an incentive fund whereby states which promptly take up their normal apportionments might receive additional Federal grants. This, however, is done only if there is urgent need for additional airport development in such states.

As an example, California serves to show benefits which might come to states from the discretionary fund. That state's 1947-48 apportionment of Federal funds for airports amounted to $2,726,618. But by aggressively planning its airports, California sought at least 60 percent more, and received tentative allocations of Federal grants in the sum of $4,425,999! This called for CAA to make tentative allocations of $1,699,381 from the 1947-48 discretionary fund. Certain other states also profited by early planning of needed airport development, receiving Federal allocations of grants-in-aid from the discretionary fund, over and above normal apportionments.

Interregional Highway System

(*Continued from page 18*)

we are, for demands on our highways are steadily increasing. Traffic volume of 360 billion vehicle-miles in 1947 is estimated to be over 5 per cent above that in 1946 and 8 per cent above the prewar high of 1941. Motor vehicle registrations, estimated at 37,116,000 for 1947, are also 8 per cent above the prewar high of 1941. The number of truck registrations, estimated at 6,500,000 in 1947, exceed the 1941 figure by one third, and the average load carried by trucks and combinations on main rural highways in 1947 was 4 per cent above that in 1946 and 37 per cent above the prewar high of 1941.

There is no indication of any immediate slackening in this growing traffic demand. Our highway plant, badly battered during the war, will be severely tested in the years ahead. Congress in the 1944 Act provided the authority to develop the master highway plan, and it is now considering extension of that authority for several years ahead. It is the responsibility of all of us concerned in any way with the administration, planning, design, construction, or operation of highways to do our part to see that plan realized. It is much later than we think.

Safety Code for Conveying Equipment

The first nationally acceptable safety provisions for the construction and operation of mechanical conveyors and conveying equipment have recently been made available, according to an announcement by Vice-Admiral George F. Hussey, Jr., USN (Retired), secretary of the American Standards Association.

The experience of a wide variety of national groups concerned with the manufacture and use of conveying equipment and with the safety of workers in plants using this equipment was called upon in preparing the recommendations. These groups were represented on the ASA committee which worked under the leadership of the National Bureau of Casualty and Surety Underwriters and the American Society of Mechanical Engineers.

Safety provisions for all types of conveyors are included in the new standard. Special provisions for safe operation are given for each type. The safety of the worker or operator is given first consideration, but the efficient use of the conveyor has also been kept in mind in selecting guards and other safety devices.

The use of mechanical conveyors, which today is a 125 million dollar business, has within the past 60 years reduced accident hazards resulting from the manual handling of material, but at the same time has introduced other risks associated with the operation of mechanical equipment. The new standard will affect the safety of workers using conveyors in such widely diversified industries as coal mining, fish packing, and ice cream manufacture. In 1946 because of the use of mechanical conveying equipment, the mining of coal averaged slightly more than 6 tons per man-day as compared with 2½ tons for a longer day in 1890 when all coal was hand mined. The recent growth of the use of conveying equip-

ment is indicated in the fact that in 1925 about 1.2 percent of the soft coal was mechanically loaded by conveyors, while in 1945, 56.0 percent was untouched by human hands. Copies of the American Standard Safety Code for Conveyors, Cableways, and Related Equipment (B20.1-1947), which costs 90 cents per copy, may be obtained from the office of the American Standards Association, 70 East 45th Street, New York 17, N. Y.

Highway Program for 1948 to Hit $1 Billion Peak

Highway programs of the 48 state highway departments and the District of Columbia call for the building of 46,821 miles of state and federal highways during 1948 at an estimated cost of $1,072,283,810, a recent survey by the American Road Builders' Association shows.

The survey, covering state and federal highway construction and maintenance for 1947 and 1948, made by D. R. Lamson, ARBA research engineer, shows that 3,414 miles of concrete roads, 25,631 miles of bituminous mixes and treated types, and 17,776 miles of other types make up the 46,821 miles to be built.

It is estimated that state highway departments will let contracts for some 27,859 miles of highways during 1948, with 48 states and the District of Columbia reporting a total of 18,962 miles of work carried over from 1947 contracts. Work carried over includes 1,290 miles of concrete pavement, 10,920 miles of bituminous mixes and treated types, and 6,752 miles of other types.

The postwar highway program is steadily gaining momentum, Mr. Lamson pointed out. Construction expenditures for Federal, state, and local highways are expected to reach $1,500,000,000 this year. Highway expenditures will represent some 40 per cent of all public construction.

Total expenditures for 1947 state maintenance in 48 states and the District of Columbia were $371,003,027, the survey shows, with expenditures for 1948 estimated at $377,693,133.

Expenditures for Federal, state, and local highway construction totaled $1,248,000,000 in 1947. Of this total $343,000,000 was local construction, $257,000,000 was state, and $648,000,000 was federal aid including matching funds. Highway maintenance cost slightly more than a billion dollars.—*Road Builders' News, June.*

State Gasoline Taxes Up 10%

State gasoline taxes were collected on 28,407,000,000 gallons of motor fuel during 1947, an increase of 2,539,000,000 gallons or nearly 10 per cent more than was taxed during 1946, according to figures compiled by the Public Roads Administration of the Federal Works Agency from motor-fuel reports of State agencies.

This gallonage does not include approximately 4,345,000,000 gallons of gasoline on which the tax either was not paid or paid at a reduced rate because the fuel was used for Government or non-highway purposes such as agriculture, industry, etc. In all, 32,751,954,000 gallons of motor fuel passed through State taxing channels during 1947 compared to 30,138,041,000 gallons in 1946.

The largest percentage of increase in gasoline consumption, based upon the number of gallons taxed at prevailing rates, was recorded in Wyoming, which reported an increase of 13,969,000 gallons or approximately 15 per cent above the 93,450,000 gallons consumed in 1946.

California again led all States in the amount of motor fuel taxed, with a total of 2,739,906,000 gallons in 1947, an increase of 303,476,000 gallons or 12.5 per cent over the 1946 figure. New York was second with a total of 1,943,409,000 gallons consumed in 1947, an increase of 150,544,000 or 8.4 per cent more than the 1946 total of 1,792,865,000 gallons. Pennsylvania was third with a total of 1,801,468,000 gallons, an increase of 9 per cent, and Texas fourth, with a total of 1,708,454,000 gallons, an increase of 10.5 over the 1946 total.

The average State gasoline tax per gallon for all States was 4.25 cents in 1947, as compared with an average tax of 4.16 cents in 1946. State gasoline tax rates last year ranged from two cents a gallon in Missouri to seven cents a gallon in Florida, Louisiana and Tennessee. The Federal tax is 1½ cents a gallon.

State motor-fuel tax collections and other receipts, such as inspection fees, dealers' license fees, fines and penalties, amounted to $1,206,901,000 in 1947, as compared with a total of $1,064,681,000 in 1946.

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